Table 5  REVENUE FROM ALTERNATE ANNUAL PLANTING REGIMES

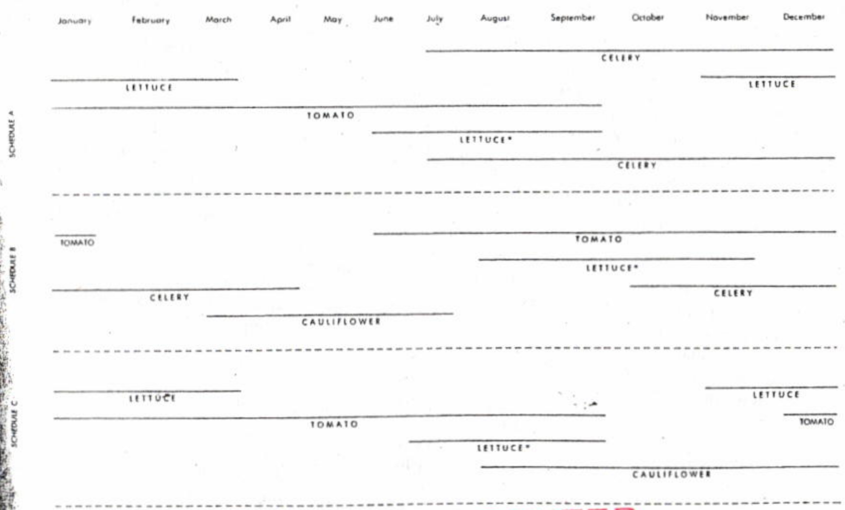
| | Retail Price | Produce/ft² | Revenue ($/ft²/yr) |
|---|---|---|---|
| SCHEDULE A: | | | |
| Celery | 89¢/bunch | 1 bunch | $0.89 |
| Tomato | avg. 69¢/lb | 4 lb | 2.76 |
| Lettuce | 69¢/head | (two) 1.9 head* | 2.62 |
| TOTAL | | | $6.27 |
| SCHEDULE B: | | | |
| Celery | 89¢/bunch | 1 bunch | $0.89 |
| Tomato* | 99¢/lb | 1.2 lb | 1.18 |
| Lettuce | 69¢/head | 1.9 head | 1.31 |
| Cauliflower | $1.89/head | 0.4 head | 0.76 |
| TOTAL | | | $4.14 |
| SCHEDULE C: | | | |
| Lettuce | 69¢/head | (two) 1.9 head* | $2.62 |
| Tomato | avg. 69¢/lb | 4 lb | 2.76 |
| Cauliflower | $1.89/head | 0.4 head | 0.76 |
| TOTAL | | | $6.14 |

*Two reasons

*Off-season price

offers the highest income at $6.27/per square foot per year; another plan may be selected to facilitate crop rotation and balance the nutrient requirements drawn from the soil. Comparing the three schedules, flexibility in crop selection is often narrowed by the premium price available at a particular season. We remind readers that with prices soaring, these prices shortly may be regarded as too conservative!

Figure 2. Alternate Annual Planting Regimes.



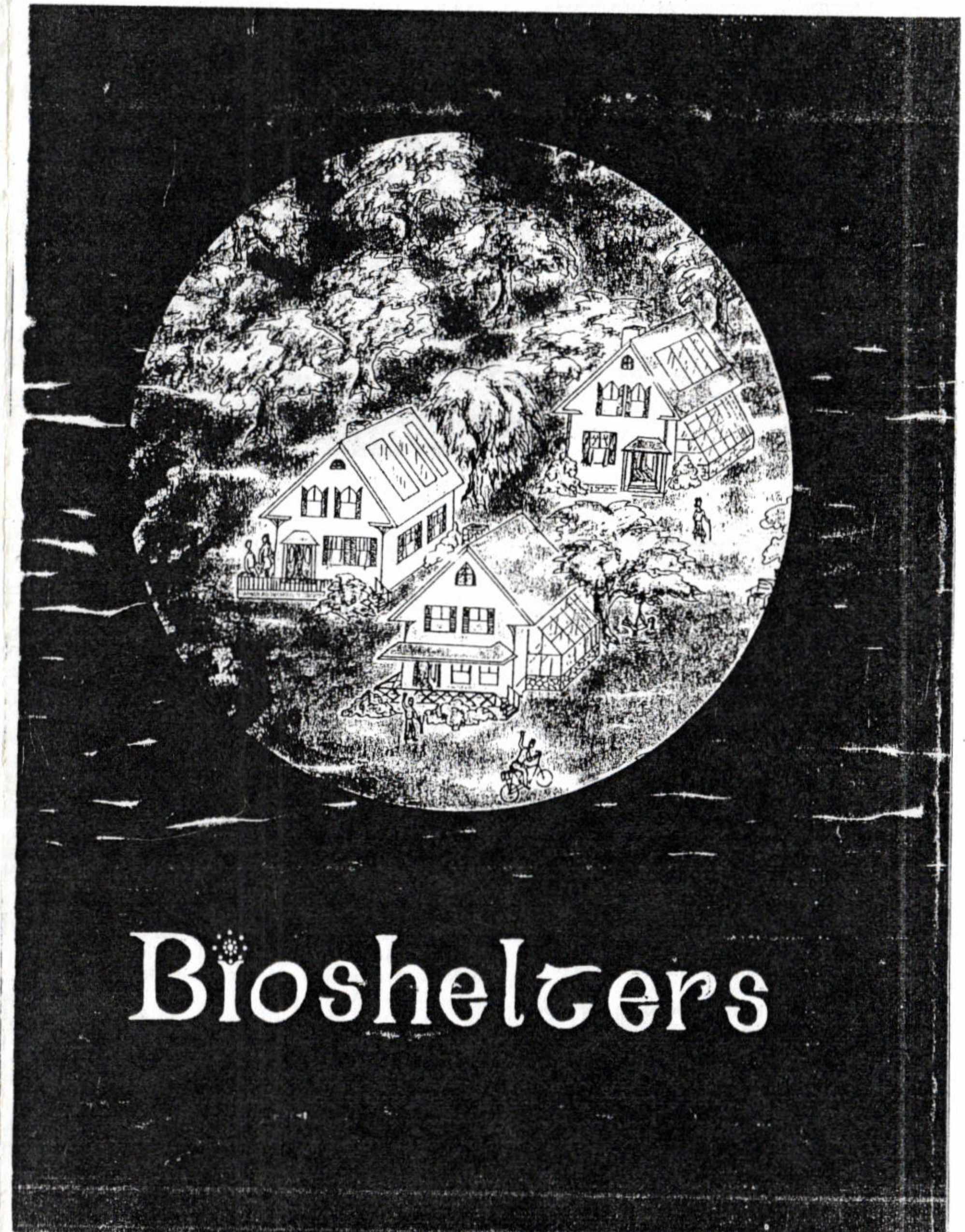

*Lettuce grown under mature tomatoes

## Biological Islands

Because crops are planted, removed, and altered from season to season, most agricultural environments are intrinsically unstable. Such instability can lead to pest outbreaks, since biological regulatory mechanisms are not usually well established. An example is the introduction of ladybird beetles (*Hippodamia convergens*) to control aphids. Once the crop is harvested, the number of aphids, which provide nourishment for the predator, is reduced. The ladybird beetle population will consequently drop or become nonexistent. In the Ark we increased ecological diversity and biological stability by creating aquatic and terrestrial microcontrol "islands" throughout the interior. These "islands" include such stable perennial plants as ginger, flowers, herbs, and grasses like bamboo that are not cropped. These in turn provide continuing habitats for pollinators, predators, and parasites of insect pests. The parasites include parasitic wasps, larvae of flies, predatory mites, spiders, frogs, and lizards. The entire island network, located in slightly suboptimal growing areas, also creates a pleasant surrounding.



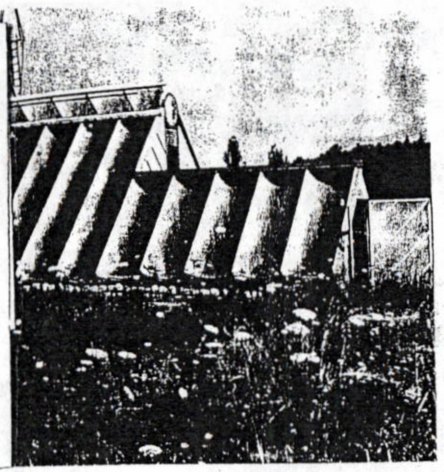




This section on bioshelters is divided into two distinct parts, the one scientific and the other more or less domestic. The first, "Logging the Course of the Ark," reflects the range of our investigatory research in the Cape Cod Ark, which, at the age of five, has earned a venerable standing among solar greenhouses. Horticulture, pest control, modeling, toxic materials, and designing future bioshelters are discussed in the light of our current knowledge.

The second part, if less scholarly, is more broadly experiential. It is written by an assortment of people who having been exposed to the Ark have incorporated a bioshelter in some form or another into their lives. Any readers contemplating doing so themselves will be interested in the variety of approaches and costs represented.

N.J.T.



Hilde Maingay

# LOGGING the COURSE of the ARK

## Indoor Gardening

*Colleen Armstrong*

One of the goals underlying the design of the Ark was to point the way toward a solar-based, year-round, employment-creating agriculture for northern climates. Our goal was to devise a food-raising ecosystem that would require one-fifth to one-tenth the capital of an orthodox farm but use far less space. Our original target was for a bioshelter-based microfarm costing $50,000, land included. The experimental prototype described on the following pages cost less.

Our strategy was to avoid mimicking and scaling down single-crop commercial farms. We adopted rather an ecological perspective, integrating into the design a blend of soft technologies, mixed crops (including greens, vegetables, flowers, fish, and other aquatic foods), and the mass propagation of trees. The microfarm was encapsulated in a solar building in which internal climate and the control of disease and pests were carried out by ecological, structural, and data-processing subcomponents. This contained ecosystem with its interrelated and interdependent components of plants, earth, insects, fish, and people is a bioshelter, which we called the Cape Cod Ark.

Sterile soils and the use of toxic chemicals for intensive management are common elements of orthodox greenhouse food culture. We opted for deep, biologically diverse soils that we "seeded" from fields, meadow, and forest environments in alluvial, limestone, and glacial areas in southern New England. The process has become a continuing one. To the soils we added compost, seaweeds for trace elements and structure, and composted leaf litter. We wanted to create soils with the following characteristics:

1. High fertility.
2. High organic matter and water-holding ability.
3. Multiple nutrient-exchange pathways and storage capabilities.
4. Optimizes carbon dioxide production through dense bacterial activities.
5. Provides shelter for diverse animal population, including earthworms and pest predators.



Table 4. VARIETAL TEST SHEET FOR TOMATOES IN CAPE COD BIOSHELTER

| Name of Variety | Days Until Maturity (from Transplant) | Average Weight per Fruit (oz) | Yield (lb/ft²) | Equivalent lb/ 1,000 ft² | New England Production (lb/ft²) | Insect Resistance | Disease* Resistance |
|---|---|---|---|---|---|---|---|
| SPRING: | | | | | | | |
| Small Fry (US) | 68 | 0.75 | 1.2 | 1,200 | — | Medium–high | Medium |
| Lito® (Holland) | 76 | 2.5 | 4.0 (double-pruned) | 4,000 | 2.5 | Medium | Medium–high |
| Tropic (US) | 82 | 2.8 | 1.8 | 1,800 | 2.5 | Medium–high | High |
| Type 127 (Holland) | 72 | 2.3 | 3.6 (double-pruned) | 3,600 | 2.5 | Medium | Medium–high |
| FALL: | | | | | | | |
| Lito® (Holland) | 78 | 2.5 | 1.2 | 1,200 | — | Medium | Medium–high |
| Tiny Tim (US) | 45 | 0.4 | 0.6 | 600 | — | Low | Medium |

*Diseases include verticillum wilt, fusarium wilt, leaf blight and anthracnose.

of fuel, many conventional tomato growers in New England have decreased production.

An evaluation of the first year of summer tomato production in the Ark showed an average of 2 lb/ft² for the 1978 season. This yield is probably low as we know part of the crop was snitched by visitors.

The following spring we evolved a more sophisticated program incorporating a valuable pruning technique. Double-pruning as it is called is a European method that incorporates a selected axial sucker or vegetative outgrowth into a second indeterminant stem. This pruning technique can double fruit yields while not affecting fruit size. It is an excellent method for maximum space utilization. We began our preliminary trials with Dutch seeds. To date, the favorite variety has been Lito* from the Rijk Zwaan Co. in Holland. This variety is slightly smaller than the average garden tomato although it tastes as sweet. Mid-March planting gave us fruit by early June and a production figure in July of an average of 5.5 lb/plant! Fruit production lasted 14 weeks with a final figure of 13 lb/plant, or 4 lb/ft², twice the yield of the first year. If the tomato area in the Ark were equivalent to 1,000 ft², Lito® could produce 4,000 lb of fruit in the spring season.

Fall tomato production also has merit in bioshelters. Again, timing is most important. Seeding begins on the first of June. Healthy plants are set in beds by the first week in August and the first tomatoes begin to ripen in mid-October. Fall fruit production is considerably less than spring production, measuring 1.2 lb/ft² compared to 4 lb/ft². However, top prices are paid at this time of year and further on into December. In the future, many additional factors such as light-reflection material, thermal curtains, and better glazing may contribute to boosting fall tomato production.

The results of our tests of several tomatoes are shown in Table 4.

### Seedling Production

Besides the deep-dug, intensive beds in the Ark, there is approximately 75 ft² of bench space that we alot to young seedlings. The area is regarded as a nursery. A germination box provides the environment for optimal seed sprouting. Young plants are transplanted into containers that hold 3–10 of a particular variety. Although small, the bench space is essential to us and is most productive in late winter and in spring. In 1979 we produced over 6,000 transplants in the Ark for New Alchemy's gardens and experimental plots. A seedling schedule indicates what vegetable and flower seedlings to grow at the proper time of year. A cycle envolves; as mature transplants are moved to the cold frame, a second set of younger seedlings assumes their space. After a few weeks, the second set is taken out to be hardened off, and a third moves into the same space. Many growers find spring the most profitable season. On Cape Cod, three tomato plants can retail at $1. With adequate timing, spring transplant profits could exceed those of any other time of year.

### Planting Regimes

Figure 2 displays three alternate vegetable-planting schedules. All can be made profitable ventures. Schedule A was the regime for the 1979/1980 season in the Ark. Table 5 lists the retail revenue per square foot using the three schedules. Schedule A

## Valuable Crops

### *Celery*

After a successful pretrial season, we cultivated celery as the main crop in the fall of 1979. Celery has a long maturing process from seed to harvest. Seed germination is approximately 21 days, an additional 45 days is required for developing as a transplant, and it is 76 more days until harvest. The advantages of growing celery in bioshelters include the long developing process, and the fact that it is a compact, verticle-axis crop. The crop occupies bedding space for 72–76 days, only about half of the total maturation time. Celery has the added advantage of being a relatively high priced, popular vegetable in American markets.

There are a few characteristics of celery that should be taken into consideration, however. It is one of the more difficult crops to grow. It is a rich feeder of nitrogen and requires an abundance of moisture from the soil. Blanching (preventing the development of color) and binding are required for a marketable crop. Offsetting such demands, celery can be spaced at one plant per square foot and weigh 1–2 pounds per plant. As of this writing it brings a retail price of 89 cents per bunch. Celery is a good storage vegetable and has a flexible harvest period. The first-year results have been encouraging, and crop evaluation will continue both in early spring and fall.

### *Tomatoes*

During seasons that tomatoes are imported, retail prices on Cape Cod approach and often exceed $1 per pound. A review of the tomato culture literature indicates that greenhouse tomatoes have two seasons: spring and fall. Predictably, the spring season—with longer photoperiod and higher luminosity—is more profitable. With the rising cost

Figure 1. Average Winter Vegetable Production in Cape Cod Bio-shelter over Six-Month Period.

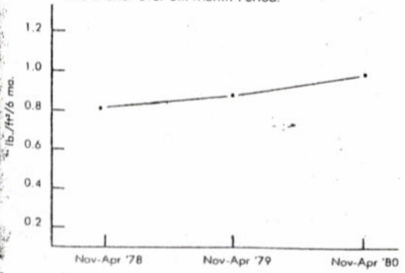



Table 3. VARIETAL TEST SHEET FOR LETTUCE IN CAPE COD BIOSHELTER.

| Name of Variety | Time to Maturity (days) | Average weight (oz/plant) | Density (oz/ft²) | Equivalent 1b/1,000 ft² | Aphid Resistance | Bacterial Soft-Rot Resistance | Heat Resistance | Tip-Burn Resistance | Color | Taste |
|---|---|---|---|---|---|---|---|---|---|---|
| Deci-Minor (Holland) | 75 | 5.4 | 10 | 625 | Medium | Medium–high | High | High | Dark green | Very good |
| Grand Rapids* loose-leaf (US) | 45 | 5.0 | 8.7 | 544 | Medium | High | Medium–low | High | Light green | Very good |
| Ostinata (US) | 60 | 4.9 | 9.3 | 581 | Medium–high | Medium | Medium–high | High | Medium green | Good |
| Prizehead loose-leaf (US) | 48 | Failed | — | — | Low | High | Low | Low | Green/red | Failed |
| Ravel RZ* (Holland) | 66 | 5.5 | 11 | 688 | High | High | High | High | Dark green | Excellent |
| Reskia* (Holland) | 74 | 8.0 | 8.2 | 512 | Medium–high | Medium | Medium | High | Light green | Very good |
| Rossini* (Holland) | 70 | 5.5 | 11 | 688 | Medium | Medium | High | High | Dark green | Very good |
| Zwaareese (Holland) | 74 | 8.0 | 8.2 | 512 | Medium–high | Medium | Low | High | Light green | Good |

*Grand Rapids Tip-Burn Tolerant Variety



Hilde Maingay

For agricultural purposes the most relevant indicator of soil fertility is the amount of produce a plant yields. In the Ark there are two important facts that should be considered when discussing soil fertility. First, the soil is the basic, essential source of plant nutrients; second, unlike the situation when seasonal cropping is practiced, the soil's nutrients are tapped 12 months of the year. We use crop rotation to balance nutrient demand. Two laboratories (Woods End Laboratory in Temple, Maine, and University of Massachusetts Suburban Experimental Station in Waltham, Massachusetts) have assisted us in evaluating our soil conditions by auditing Ark soil samples. Table 1 summarizes the basic composition and development of the Ark's soil over a two year period. A steady accumulation of organic matter and improved carbon: nitrogen ratio is attributed to cyclic introduction of properly composted material. Mineral levels fluctuate upon various demands of specific crops. Such reports are vital when selected crops are heavy feeders and possible nutrient deficiencies may arise.

Soil fertility is maintained through a process of annual innoculation. In September, after the summer season has come to a close, each bed is turned with well-decomposed organic matter. This rein-

Table 1. SUMMARY OF ORGANIC MATTER AND MINERAL CONTENT OF CAPE COD BIOSHELTER'S SOIL, 1977–1979 ª

| | | Date | | |
|---|---|---|---|---|
| | | 11/77 | 11/78 | 6/79 |
| Planned use | | Leaf vegetables | Leaf vegetables | Tomatoes |
| Texture | | Sandy loam | Sandy loam | Sandy loam |
| Organic matter | | 5.5% | 8.1% | 8.7% |
| Humus | | 3.8% | 4.9% | 5.7% |
| CEC (Meq/100 g)ᵇ | | 18.8 | 20.7 | 17.6 |
| Soil pH | | 7.0 | 6.4 | 7.0 |
| C:N balance | | Good | Very good | Excellent |
| | | 11/77 | 11/78 | 6/79 |
| Available Nutrients | | | | |
| Nutrient Anions (1b/A)ᶜ | | | | |
| Nitrogen ($NO_3$) annual releases | Desired level | 100 | 100 | 200 |
| | Level found | 90–139 M | 130–170 M | 240 M |
| $P_2O_5$ reserve phosphorus | Desired level | 350 | 250 | 130 |
| | Level found | 700 H | 760 MH | 660 MH |
| Exchangeable Cations (1b/A) | | | | |
| Calcium | Desired level | 4,900 | 5,800 | 4,900 |
| | Level found | 6,200 | 6,100 | 5,300 |
| | Saturation | 82% H | 73% M | 76% MH |
| Magnesium | Desired level | 670 | 600 | 570 |
| | Level found | 580 | 1,000 | 830 |
| | Saturation | 13% M | 20% H | 20% MH |
| Potassium | Desired level | 370 | 320 | 280 |
| | Level found | 570 | 590 | 590 |
| | Saturation | 4% M | 4% MH | 4% M |

ªPrivate circulation of Woods End Laboratory, RFD Box 65, Temple, Maine.
ᵇCation exchange capacity: a measure of the soil's capacity for holding available cations in reserve. Meq/100 g means milli-equivalent weights per 100 grams of soil; a milli-equivalent weight is the weight of a cation which exchanges with one equivalent weight or one gram of hydrogen.
ᶜ1b/A = pounds per Acre
H = High
M = Medium
MH = Medium-High

states many microorganisms that break down organic matter with steady nutrient and mineral release. In addition, an irrigation program using the warm fish-pond water continually provides soluble nitrate-nitrogen, ammonium-nitrogen, and phosphate compounds.

## Winter Crop Varieties

Over the past four winter seasons, from November through April, we have been evaluating many vegetable and flower varieties for their performance in the Ark. The Ark shares a number of characteristics with other passive solar greenhouses, but it is a bioshelter—a solar greenhouse with a difference. There are several qualities that distinguish it from other greenhouse environments. The primary difference lies in the concept of the Ark as an enclosed ecosystem, rich in diverse organisms. The practices of agriculture, aquaculture, and soil and insect ecology are all interdependent. When regulating the climate of the Ark, we must consider the living components. Fish can be more sensitive to thermal change than plants, and seasonal plants may require specific soil and air temperatures. The Ark may not provide optimal growing conditions for certain vegetable and flowers. Consequently, varieties must be chosen with these factors in mind.

In the Ark the average soil temperature at a 2 inch depth during the coldest months is as follows: November, 60° F; December, 59.5° F; January, 55° F; February, 59° F; March, 62° F. Average soil temperatures for two periods of November through April in 1977, 1978 and 1979 were 59° F at a depth of 2 inches, 54.1° F at 6 inches, and 53.2° F at 12 inches.

Although the soil beds provide more than sufficient temperatures for bountiful winter vegetable production, they are also considered a portion of the total thermal mass. The air temperatures fluctuate. Clear, sunny days will raise the daytime air temperature to 77° F, whereas on cloudy days it tends to drop to 55°–60° F. With an average minimum air temperature of 49.2° F and an average maximum air temperature of 70.8° F, the Ark's climate is similar to that of spring in a temperate zone. At this time, many foliage and root crops can be cultivated. The Ark provides an average of 25 portions of salad greens per day during the winter season. What better time to have access to fresh vegetables, rich in good nutrition?

Before we select which vegetables to grow, we give careful thought to each garden bed. These are a few of the questions we ask to make the most reasonable selections.

### *What is the size of the garden bed?*

In the Ark, all of the beds are 5 feet or less in width and can be planted intensively. However, each bed borders a pathway and in our case must be able to take the abuse of reckless visitors and gardeners. Many dwarf flowering plants such as marigolds, alyssum, and lobelia make excellent borders, and we make use of them as such. A few hardy plants like beets, celery, parsley, and thyme can be employed as fences. Smaller areas should be planted with compact foliage crops that can be harvested by leaf. Loose-leaf lettuce, endive, celery, and chard can be planted close to one another and picked continuously for weeks. Larger beds offer freedom for all kinds of intercropping with broccoli, cauliflower, chard, kale, head lettuce, and herbs.

### *What is the quality of light striking the garden bed?*

This is the most important question. Light can range from full through partly shaded, lightly shaded to deeply shaded. Full light exists when direct sunlight is present throughout the day. Moving down the scale, a partly shaded area has direct light for only a portion of the day. Light shade prevails when no direct sunlight reaches the bed, but a high light intensity is maintained. Deep shade is an extreme case in which there is low light intensity at all times.

Throughout the winter season, most vegetables require full light. Real sunworshippers are celery, head lettuce, leeks, broccoli, cauliflower, beets, dill, and thyme. Vegetables that will produce in partly or lightly shaded areas are endive, chard, parsley, kale, and Chinese greens. A few exceptional foliage crops continue to produce throught he dead of winter. They are endive, parsely, New Zealand spinach, beet greens, and both Swiss and red chard.

### *What is the condition of the soil?*

A steady program to build and maintain soil fertility is an inherent part of our gardening practice. However, it's important to recognize that some crops are heavy feeders, and crop rotation should be employed.

Some vegetables may need additional compost dressing. If light conditions are stressing, a balanced rich soil and good air circulation will assist the plant to retain strength and will minimize pest problems.



Table 2. SUITABLE WINTER VEGETABLE VARIETIES FOR BIOSHELTERS IN NEW ENGLAND

| Vegetable | Name of Variety | Seed Co. | Transplant/Seed | Fall/Spring |
|---|---|---|---|---|
| Beet | Early Wonder Tall Top | Johnny's | Transplant | F |
| | Green Top Bunching | Stokes | Transplant | F |
| Broccoli | Cleopatra | Stokes | Transplant | F |
| | Ce Cicco | Johnny's | Transplant | S |
| Celery | Utah 52–70R Improved | Johnny's | Transplant | F & S |
| Chard, red | Burpee's Rhubarb* | Burpee | Transplant | F & S |
| Chard, Swiss | Fordhook Giant | Stokes | Transplant | F & S |
| Cauliflower | Opaal* | Rijk Zwaan | Transplant | F |
| Cabbage Chinese | Matsusitima | Johnny's | Transplant | F |
| | Chinese Pac Choi | Johnny's | Transplant | F & S |
| Endive | Full Heart Batavian | Johnny's | Transplant | F |
| | Green Curled | Stokes | Transplant | F |
| Kale | Harvester LD | Johnny's | Transplant | F & S |
| | Green Curled Scotch | Stokes | Transplant | F & S |
| Lettuce, Bibb type | Ravel RZ* | Rijk Zwaan | Transplant | F & S |
| | Rossini* | Rijk Zwaan | Transplant | F & S |
| | Ostinata | Stokes | Transplant | F & S |
| | | | | F & S |
| Lettuce, head | Reskia RZ* | Rijk Zwaan | Transplant | S |
| | Zwaareese* | Rijk Zwaan | Transplant | F & S |
| Lettuce, loose-leaf | Grand Rapids Tip-burn Resistant | Stokes | Transplant | S |
| Parsley | Champion Moss Curled | Stokes | Transplant | F & S |
| | Plain Dark Green Italian | Stokes | Transplant | F & S |
| Spinach | New Zealand (perennial) | Stokes | Seed | F |
| | Malabar | Burpee | Seed Transplant | S |

### *What vegetables should be given priority?*

Criteria for choosing vegetables are that they please the intended consumer and are nutritionally complementary. A short story might be pertinent. A few years ago, we grew lots of New Zealand spinach. It was fabulous for re-enforcing the rock walls and was a nonstop producer. Unfortunately, only the most reckless of greens aficionados would chew it, sometimes with reluctance. Rumors developed that most of it was going to chickens and goats. Graffiti such as "Yuck" began to appear in the tally book. It seems sturdiness and nutritional value cannot stand alone. At least not with us.[1]

We have experimented with varieties of lettuce, endive, celery, chard, beet, brassicas, spinach, and parsley to ascertain which vegetables are most adapted to the thermal and light regimes inside the Ark. While a few crop varieties demand a specific season, most of the foliage crops can be cultivated throughout this cool period. See Table 2. Lettuce varieties from Holland have proved superior to domestic varieties. It is possible that Dutch greenhouse crop-breeding conditions may more closely approximate conditions in bioshelter environments in northeastern United States. We set the following criteria for our varietal tests. Each variety of lettuce was rated for number of days until maturity, average ounces per plant, ounces per square foot, color, aphid resistance, disease and heat resistance, tip-burn and taste (see Table 3).

Undoubtedly, Ravel R2®, a bibb lettuce with outstanding qualities, is our favorite, most productive variety in the Ark. Grand Rapids Tip-Burn Tolerant is the preferred loose-leaf lettuce however; most of the bibb lettuces give higher yields per square foot.

Our vetetable production can be divided into two categories: overall production from the 517 square foot ($ft^2$) growing area, and optimal production from testing areas (Tables 3 and 4). Over a three-year period, we have brought about several changes in the growing area. In fall 1978, we placed three solar-algae ponds in areas of low light, providing additional heat storage, accessible pond water, and warmer temperatures in the soil surrounding the ponds. At the same time, we designated a 35 $ft^2$ plot as a permanent area for tropical plants; this serves as an animal and insect sanctuary.

Figure 1 shows the six-month winter vegetable production from the 517 $ft^2$ area over a three-year period. The vegetables included lettuce, endive, tomatoes, celery, brassicas, chards, beets, and herbs.

[1]For readers uninitiated to New Zealand spinach, ruminating briefly on a rusty nail will provide a fair analogue of the taste, if not the texture, of sampling the real thing. *Ed.*